AOS 103

Week 9 Discussion

Internal Waves

1) What type of conditions are necessary for internal wave propagation?

2) What is the medium on which internal waves propagate?

3) What types of processes can generate internal waves?

4) What is the restoring force that is involved in internal wave propagation (sketch and write an equation for the sketch)

5) For 2 density layers of equal depth:
    1) What are the internal wave phase and group speeds?
    2) Are these internal waves dispersive?
    3) What can we say about the relation of phase and group speed with depth?
    4) How do the long and short waves behave for this regime?

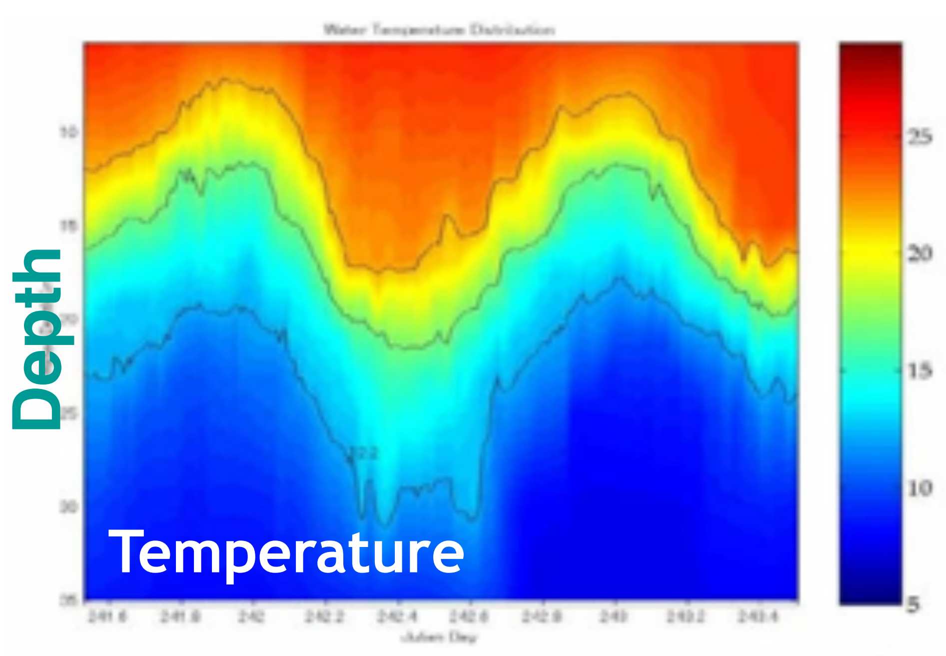
1) What type of conditions are necessary for internal wave propagation?

Internal waves (generally) need <u>stratification</u> to propagate. That is, there needs to be a gravitationally stable “layering” of density with depth (light over heavy).

2) What is the medium on which internal waves propagate?

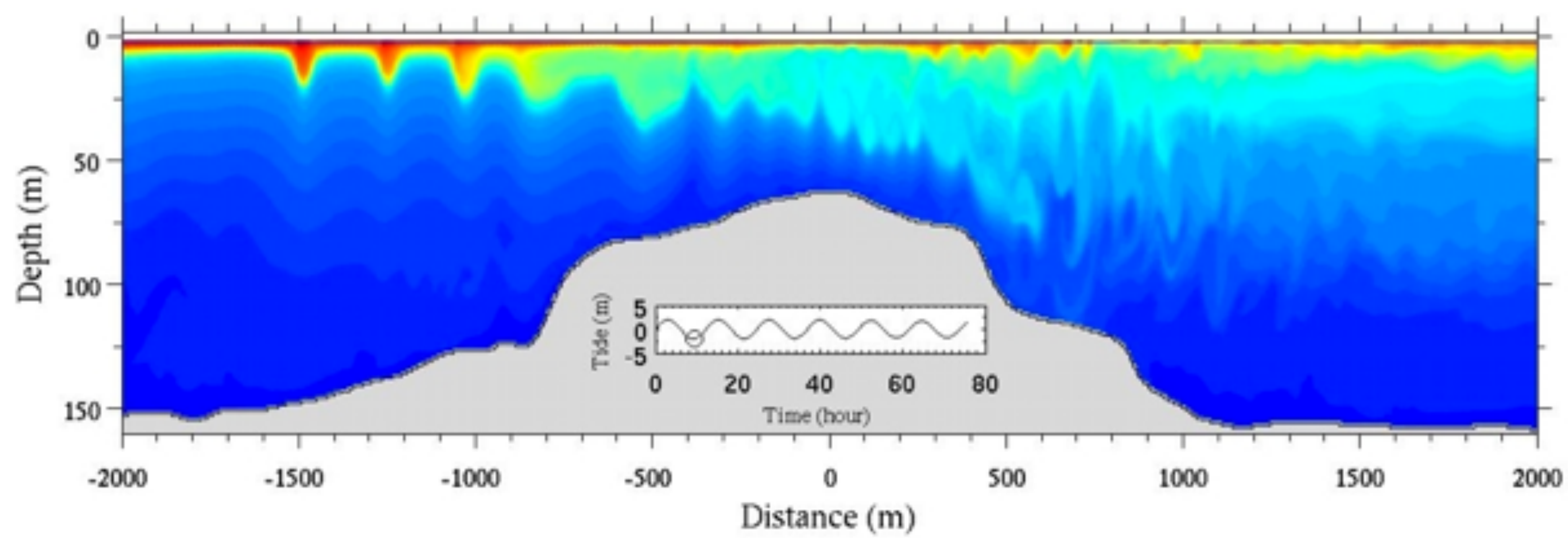
Internal waves propagate along a density (i.e., temperature and salinity) interface. They can be visualized by looking for undulations of isopycnals, isotherms or isohalines

(Time,Depth) View



Time

(Distance,Depth) View

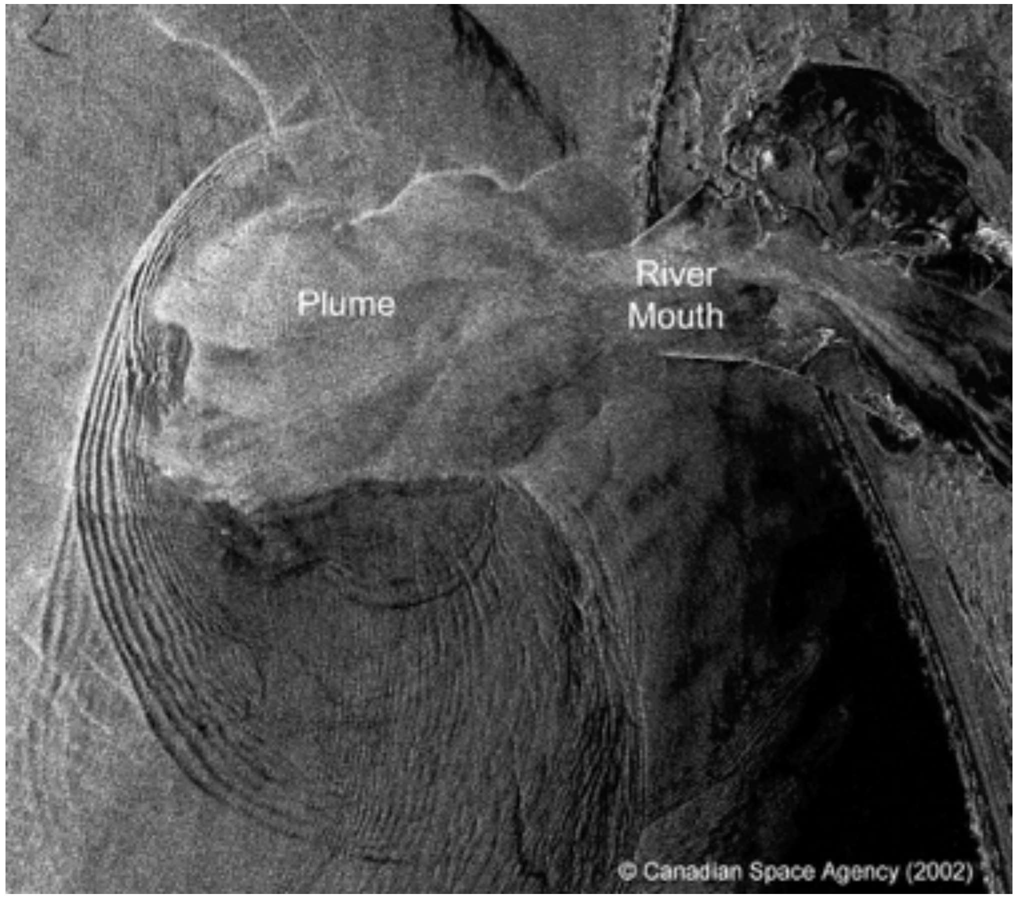


3) What types of processes can generate internal waves?

Generally, internal waves are generated by <u>flows over variable topography.</u>

On the continental shelf this can commonly be due to tidal flow, but can also be due to currents flowing in a stratified regime that somehow cause a displacement of a density surface (and trigger the buoyant restoring force)

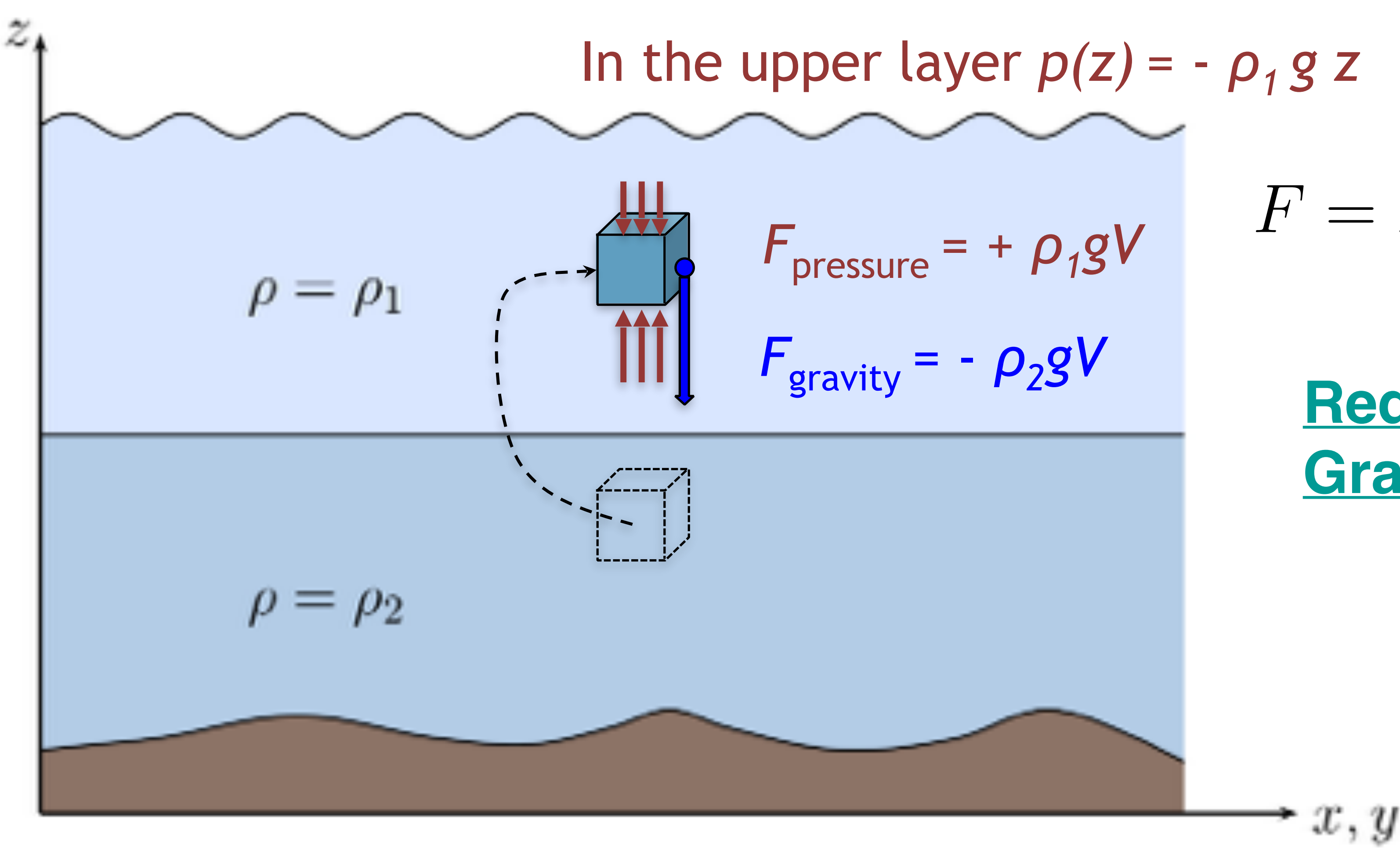
[Internal Wave Movie]



Estuarine inlets (like the Columbia River inlet shown on the left) are usually very active internal wave sites because of the strong stratification and tidal flow ebbing and flooding back and forth through the inlet

4) **What is the restoring force that is involved in internal wave propagation (sketch and write an equation for the sketch)**

The restoring force is the <u>buoyant restoring force</u>: it is analogous to gravity (for surface waves) and is essentially the downward force that fluid parcels feel in a stratified medium. The buoyant restoring force is a function of gravity and the density difference between 2 layers



$$F = F_{pressure} + F_{gravity} = (\rho_1 - \rho_2)\, gV$$

<u>Reduced Gravity</u>

$$g' = \frac{g\,(\rho_2 - \rho_1)}{\rho_2}$$

5) For 2 density layers of equal depth:

1) What are the internal wave phase and group speeds?
2) Are these internal waves dispersive?
3) What can we say about the relation of phase and group speed with depth?
4) How do the long and short waves behave for this regime?

$$C_p = \sqrt{\frac{g' H_1 H_2}{H_1 + H_2}}$$

$$H_1 = H_2 = \frac{H}{2}$$

$$C_p = \frac{1}{2}\sqrt{g' H}$$

$$\omega = C_p k = \frac{k}{2}\sqrt{g' H}$$

$$C_g = \frac{\partial \omega}{\partial k} = \frac{1}{2}\sqrt{g' H}$$

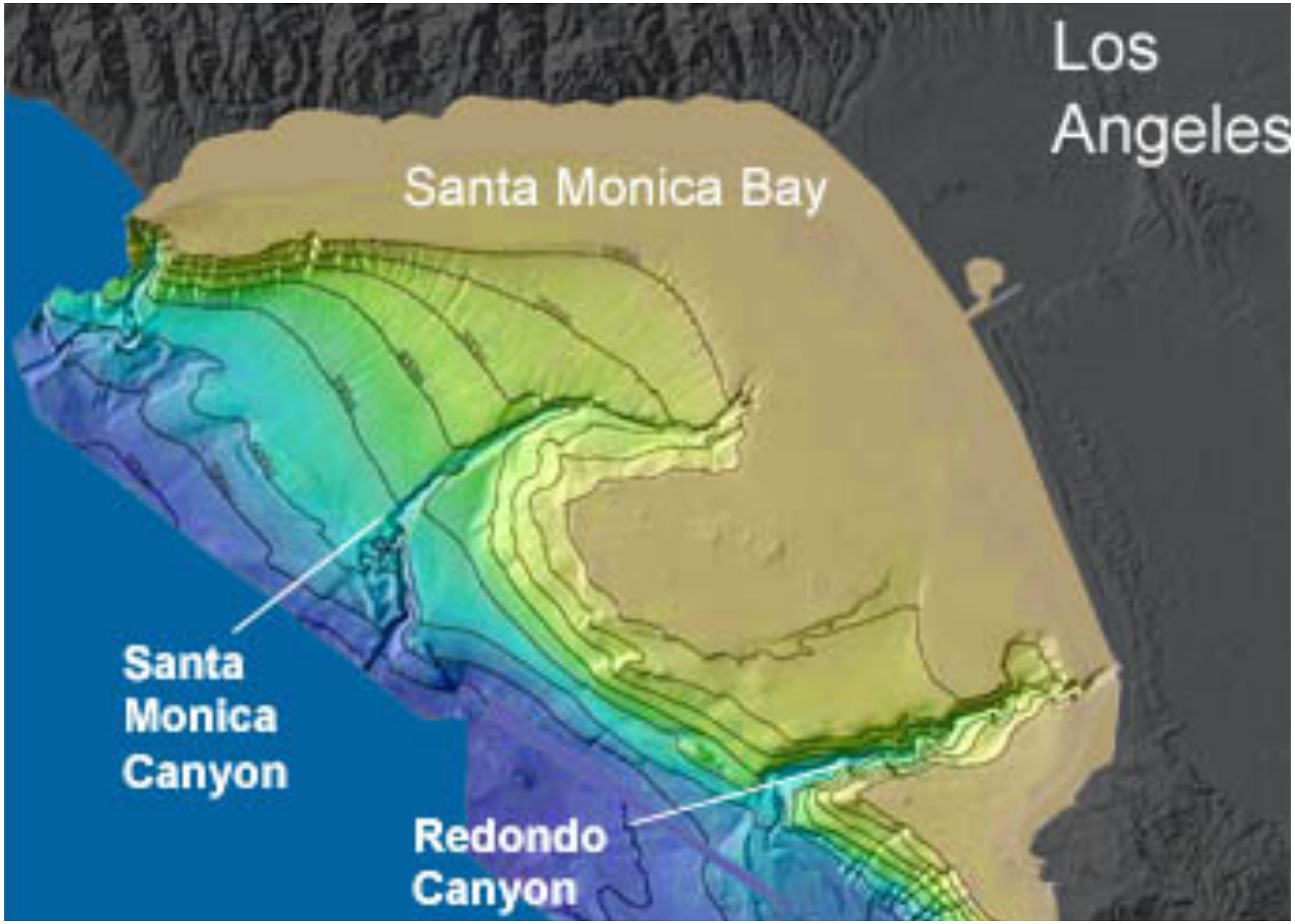
The waves are not dispersive because the group speed quals the phase speed.

Phase and group speed (for a constant reduced gravity), will increase with an increase in depth (H).

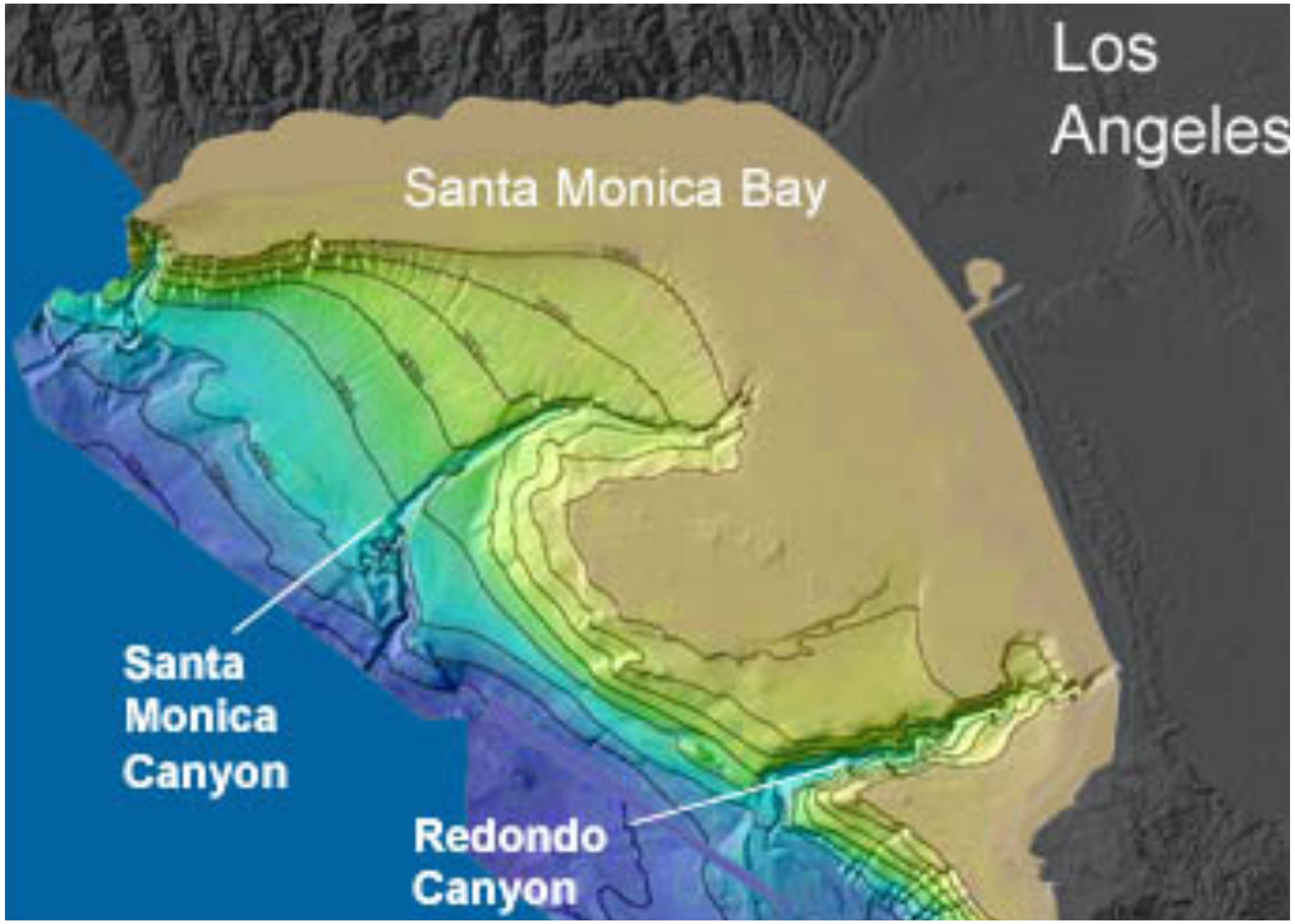
The long and short waves travel at the same speeds because the phase and group speeds are independent of wavenumber(i.e., wavelength)

Coastal Ocean

1) **Where would a potential vorticity (PV) conserving slope current flow in Santa Monica Bay?**



1) Where would a potential vorticity (PV) conserving slope current flow in Santa Monica Bay?



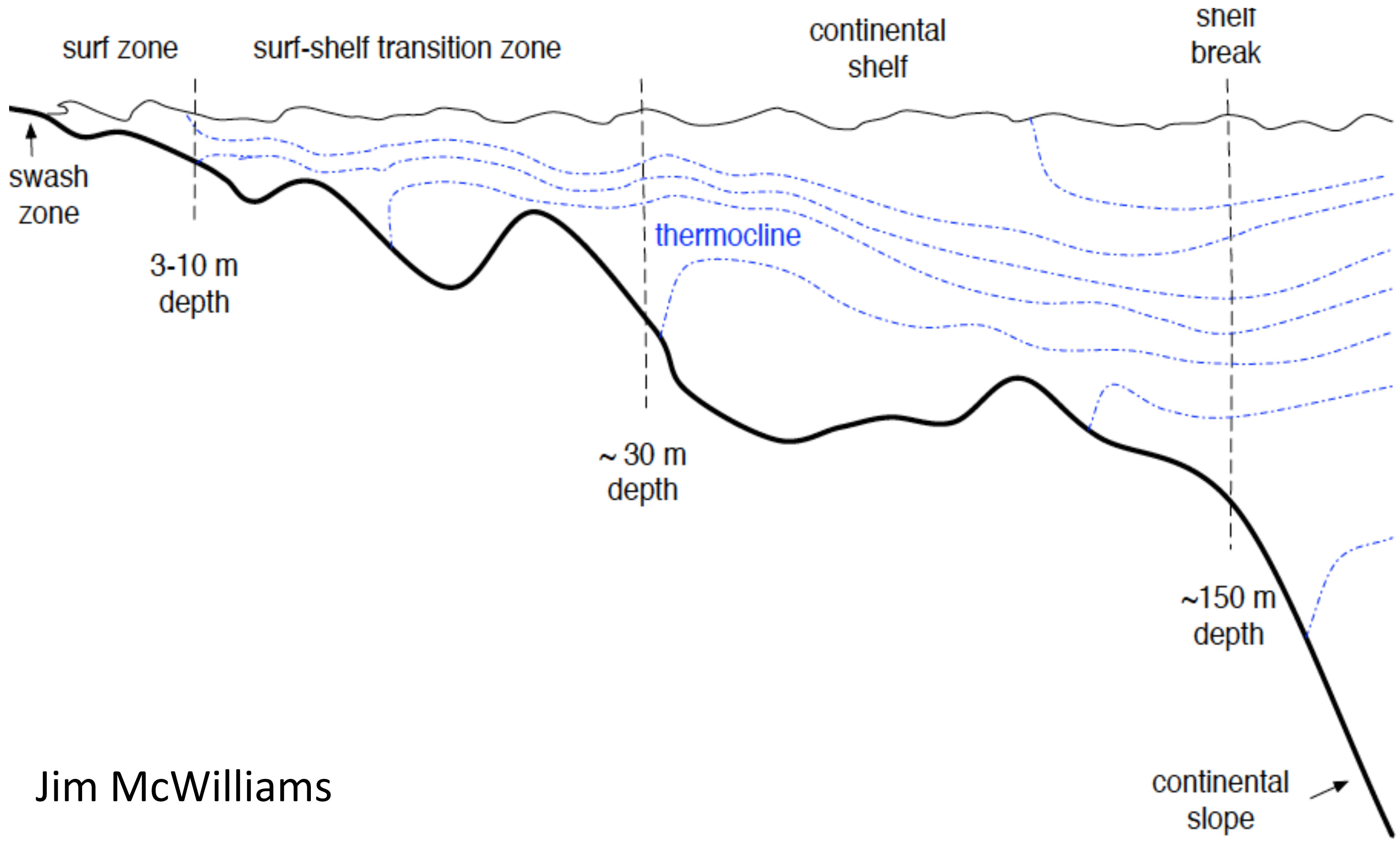
$$q = \frac{f + \zeta}{H}$$

A <u>slope current</u> would flow <u>on the slope.</u> The reason it flows on the slope is the water parcels in the current want to conserve their potential vorticity (PV) and do not want to change their depth (H), so the current stays on a line of equal depth.

On the slope (indicated on the right by the locations where isobaths get very close to each other), the depth (H) can change with very little lateral displacement (i.e., if you move up the slope a bit you get very shallow very quick). So the (H) term in PV can change by a lot even for a small movement on- or offshore

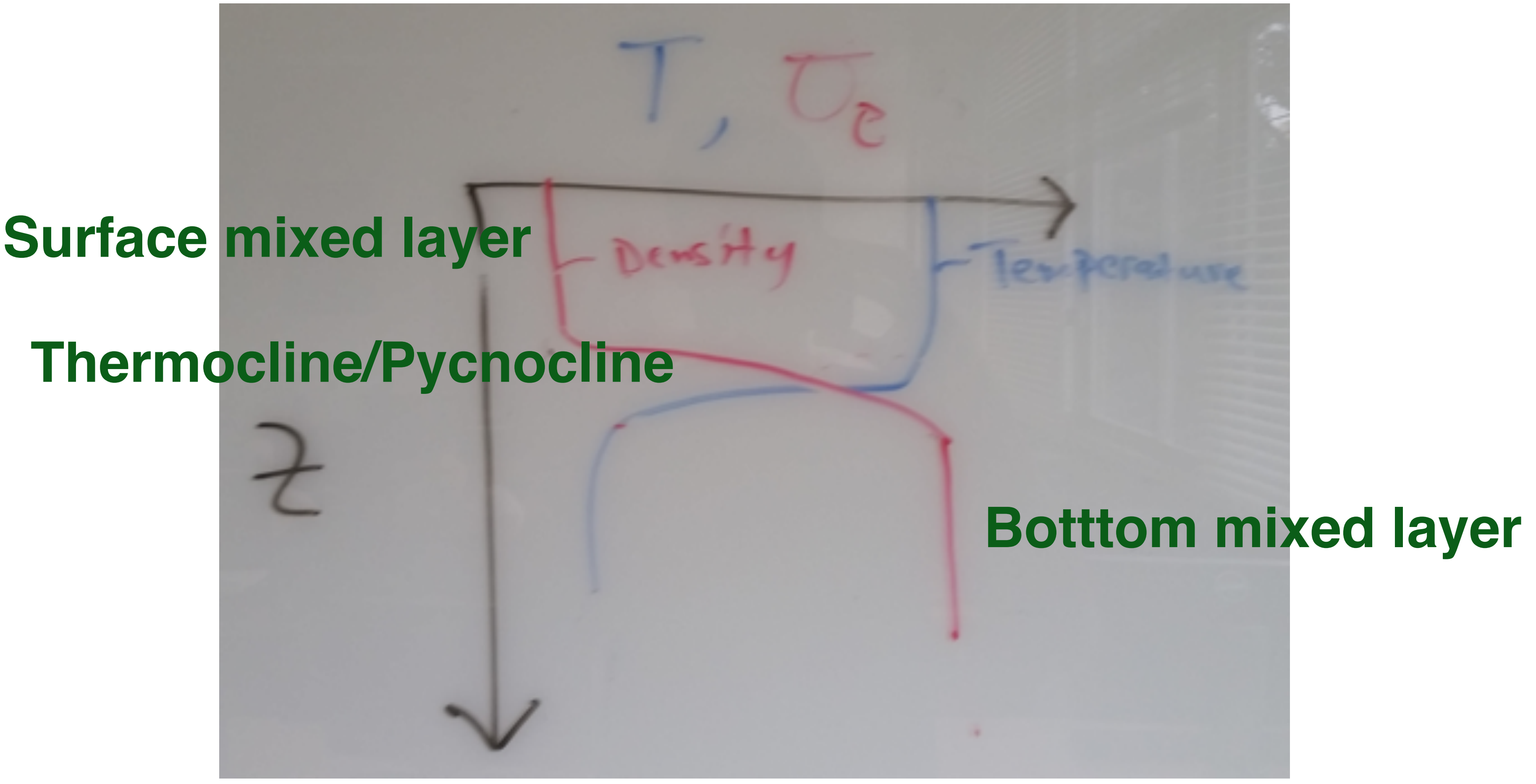
Coastal Ocean

2) **What do a vertical profiles of temperature and density look like on the continental shelf (where are the mixed layers, is there a thermocline)?**



Jim McWilliams

2) What do a vertical profiles of temperature and density look like on the continental shelf (where are the mixed layers, is there a thermocline)?



The shelf is unique in the sense that it has BOTH surface AND bottom mixed layer.

The presence of a bottom mixed layer is due to the relatively shallow depths (~10-100m). It is possible for substantial currents to exist at these depths and be in contact with the bottom, which creates bottom stresses which can drive vertical mixing

Coastal Ocean

3) How do waves (shallow-water surface waves) approaching the beach at an angle behave (and why)?

4) Do you expect stronger wave activity in headlands or bays?

5) What is the fundamental cause of wave breaking?

6) Using the relation for phase speed of shallow-water surface gravity waves explain why these waves break when they get to shore (assuming their period remains constant)

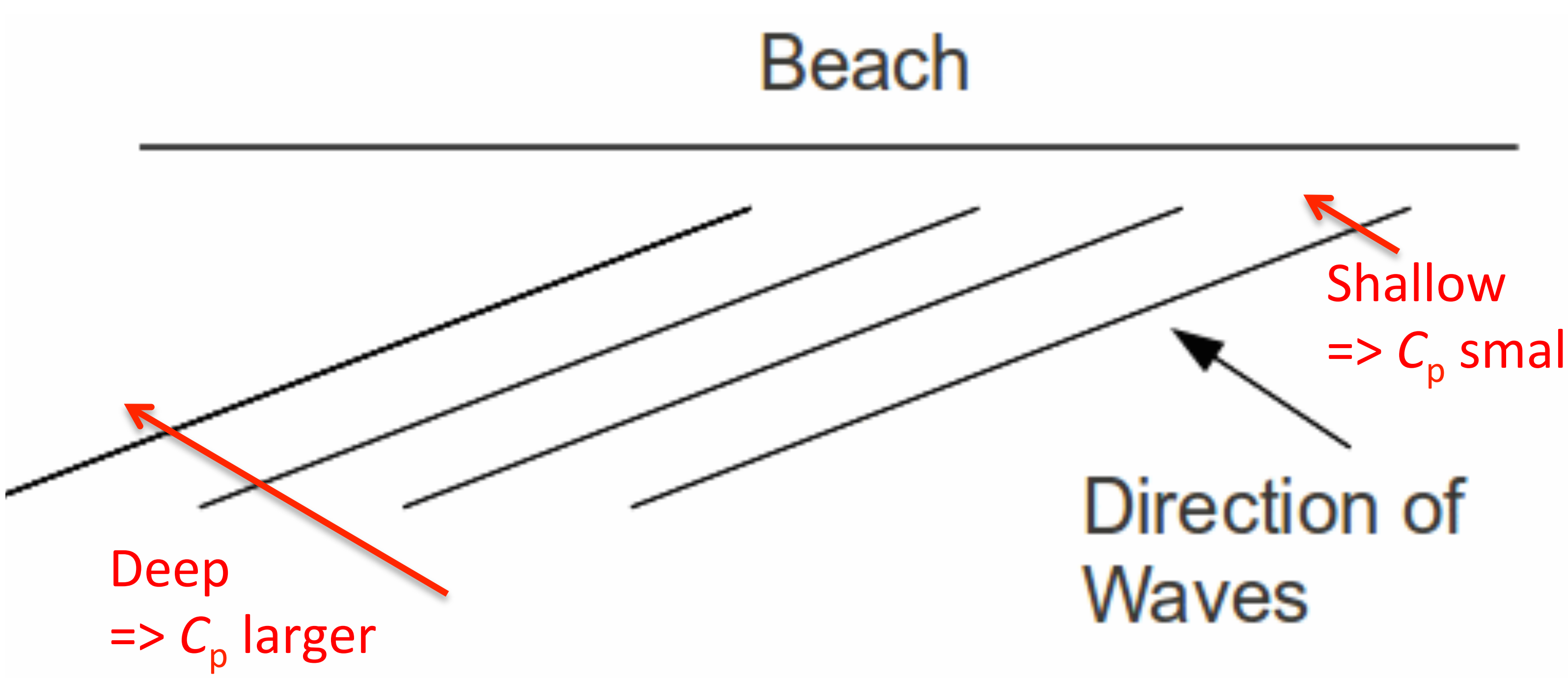
7) Bonus: if you were standing at the shoreline and looking along the beach (not at the water), how could you tell where there is a rip current based on the sand?

3) **How do waves(shallow-water surface waves) approaching the beach at an angle behave (and why)?**

As waves approach a beach at an angle they <u>refract:</u> that is, they bend parallel to the shore.

This is because the phase speed of the waves closest to shore is slower than the phase speed of the wave further from shore (because of small depth (H) nearshore relative to offshore)

$$c_p = (gH)^{1/2}$$

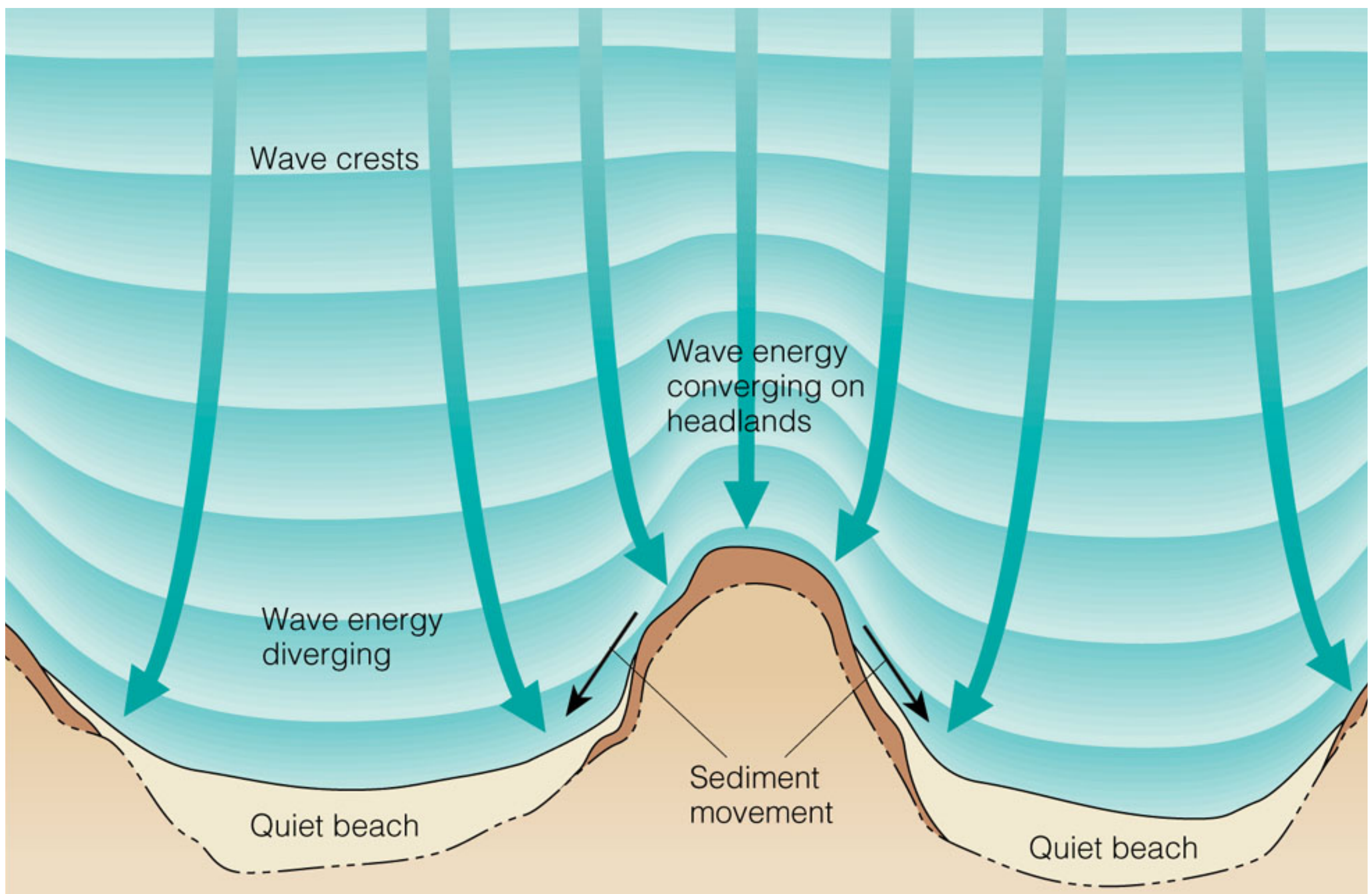


4) Do you expect stronger wave activity in headlands or bays?

We expect stronger wave activity at headlands.

This expectation is rooted in refraction.

Headlands stick out relative to the rest of the coast and thus are subject to a convergence of wave energy



5) What is the fundamental cause of wave breaking?

The fundamental cause of wave breaking is an increase in steepness of the waves. When waves become too steep, they break.

6) **Using the relation for phase speed of shallow-water surface gravity waves explain why these waves break when they get to shore (assuming their period remains constant)**

$$C_p = \sqrt{gH}$$

The phase speed of shallow-water surface waves is only variable with depth (H)

$$\omega = C_p k = \sqrt{gH}k$$

$$\omega = \text{constant}$$

As waves approach shore, the depth decreases:

$$H \to 0$$

If frequency is constant, the wavenumber must increase with a decrease in depth:

$$k \uparrow$$

Steepness will increase if wavenumber increases:

$$ak \uparrow$$

Once the wave becomes too steep it will break (and all the wave equations/assumptions we have been working with are thrown out the window)

7) **Bonus: if you were standing at the shoreline and looking along the beach (not at the water), how could you tell where there is a rip current based on the sand?**

Rip currents occur where there is a convergence of mass transport by waves on the shoreline and they flow seaward in at these places via deep channels. The rip currents can "carve out" these deep channels into the sand in the swash zone that would be visible from the shoreline. This channel can either be visible through the high-tide line or an actual "valley" in the sand on the shoreline that is the channel itself